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Calibration of Radiation Codes in Climate Models: Comparison of Calculations with Observations from the SPECTral Radiation Experiment (SPECTRE)

R. G. Ellingson, W. J. Wiscombe, J. DeLuisi, H. Melfi, and W. Smith

Department of Meteorology
University of Maryland
College Park, MD 20742

Introduction

The primary goal of SPECTRE is to:

close the loopholes by which longwave radiation models have eluded incisive comparisons with measurements.

Likewise, the experimental approach was quite simple in concept, namely:

Accurately measure the zenith infrared radiance at high spectral resolution while simultaneously profiling the radiatively important atmospheric properties with conventional and remote sensing devices

The field phase of SPECTRE was carried out as part of FIRE Cirrus II, and detailed spectra of the downwelling radiance were obtained by several interferometers simultaneous to the measurement of the optical properties of the atmosphere. We are now well along in the process of analyzing the data and calibrating radiation codes so that they may be used more effectively in climate related studies. The calibration is being done with models ranging from the most detailed (line-by-line) to the broad-band parameterizations used in climate models. This paper summarizes our progress in the calibration for clear-sky conditions. When this stage is completed, we will move on to the calibration for cirrus conditions.

Line-by-line Studies

We have begun to compare clear-sky spectra of the downwelling radiance at the surface observed during SPECTRE with FASCOD3P and with narrow-and-broad band radiation models. The mean difference between the observed and FASCOD3P calculated radiance for 26 different spectra is shown in Fig. 1a. In general, the line-by-line model captures most of the features in the observed clear-sky spectra. There is a tendency for the model to underestimate the observed radiance in the window region between 800 to 1000 cm^{-1} and to overestimate it in portions of the 1200 to 1400 cm^{-1} region. The differences in many locations is the order or smaller than the estimated absolute accuracy of the observations (~ 1.5 units on Fig. 1), but we are not yet in the position to make firm conclusions concerning the spectral and absolute character of the differences because the final instrument calibration is not yet complete.

The differences between the observed and calculated spectra in the 800 to 1000 cm^{-1} region for the highest water vapor amounts seen during SPECTRE show that the FASCOD continuum yields better results than the one of Roberts et al. (1976). The data from the drier cases can not be use to support this conclusion at this time because the absolute error of the observations is larger than the radiance in the more transparent regions of the 800 to 1000 cm^{-1} region. As the instrument calibration is completed, it will be

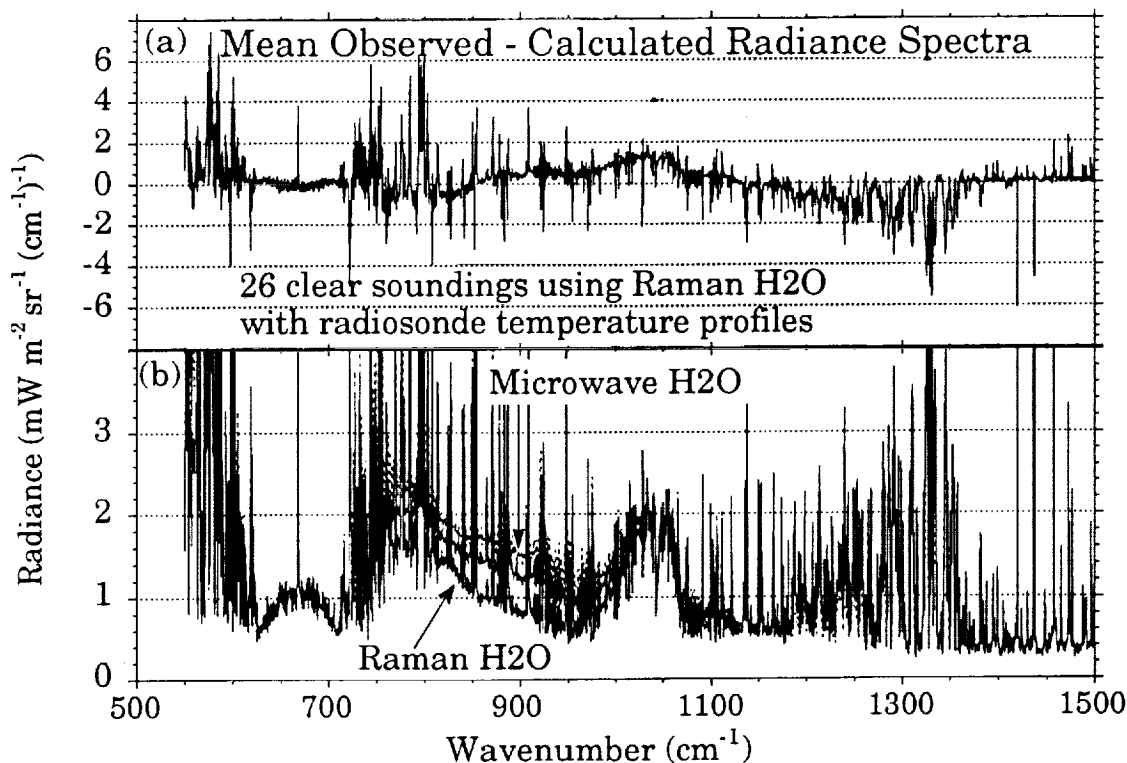


Fig. 1. Mean (a) and rms (b) AERI observed minus FASCOD3P calculated radiance spectra from SPECTRE. The calculations were performed using near simultaneous radiosonde temperature and Raman water vapor profiles with surface based trace gas data and the 1992 line compilation as input.

possible to use the high relative accuracy to check the spectral signatures of the differences and to put error bars on them. Nevertheless, the preliminary indications are that this model may be used to calibrate radiation codes used in climate models.

We recently completed 26 sets of comparisons of AERI observations with FASCOD calculations using near simultaneous water vapor profiles from radiosondes, Westwater's microwave radiometer and Melfi's Raman lidar. The spectral distribution of the rms differences (Fig. 1b) show that the Raman data yield a more consistent spectral pattern of differences between observations and calculations than occurs when the radiosonde or microwave data are used in the calculations. As the calibration of the AERI is finalized, it will be possible to use the high relative accuracy of the observations to check the spectral signatures of the differences between observations and calculations and to put better error bars on the absolute differences. The improved calibration data and CART site observations over larger water vapor amounts should allow more stringent tests of the continuum formulations than possible heretofore, particularly if a Raman lidar is used for profiling water vapor.

We have estimated the flux uncertainty of FASCOD relative to the observations in the 550 to 1500 cm^{-1} interval by using model calculations for the angular variations. The comparisons for 26 different spectra yield a mean (observed - calculated) flux uncertainty of the calculations of $0.4 \pm 0.2 \text{ W} \cdot \text{m}^{-2}$. The data do not allow us to estimate the uncertainties in the 0 to 550 cm^{-1} region. However, since this portion of the spectrum is nearly opaque

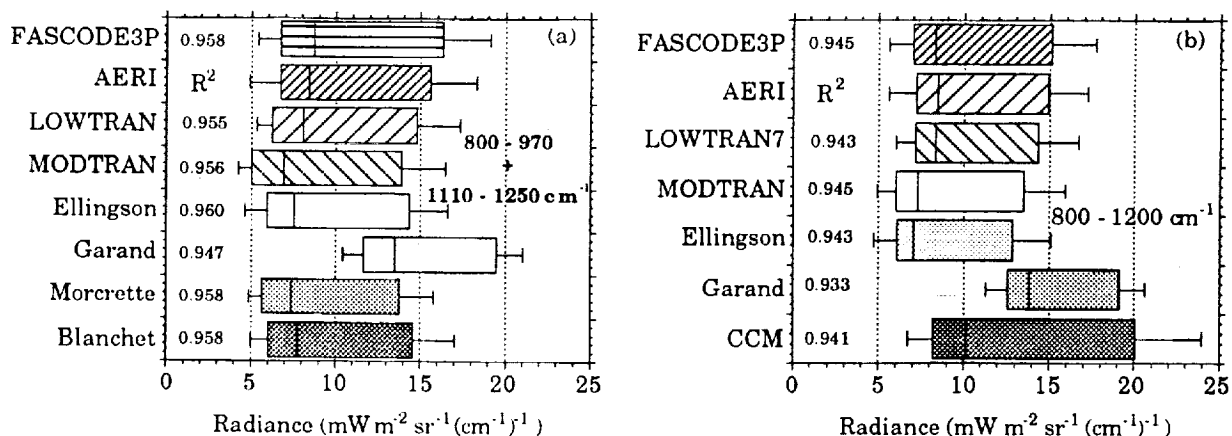


Fig. 2. Distributions of vertically downwelling radiance at the surface for 26 clear-sky cases as calculated by several different models and observed by the AERI during SPECTRE. The vertical lines in the boxes show the median values. The edges of the boxes mark the limits of $\pm 25\%$ of the population, and the lines extending from the boxes mark the minimum and maximum values. The fraction of the AERI variance explained by each model is shown in the column marked R^2 .

for the conditions we observed during SPECTRE, the uncertainties in calculating the downward flux at the surface from this portion of the spectrum are relatively small. Since the uncertainties in the interferometer data are smaller than those associated with the pyrgeometers, we believe that the interferometer-based flux data will serve as a baseline calibration of the pyrgeometers for homogeneous clear or cloudy conditions.

A disturbing trend of the differences between the AERI "observed" and FASCOD fluxes is that differences become more negative as the total precipitable water (PW) increases, independent of the source of water vapor data. The calculated flux (integrated radiance for the 550 to 1500 cm^{-1} region) is greater than that observed for 6 of the 9 cases with $\text{PW} > 1.4$ cm. These differences appear to be correlated primarily with PW in the 1100 - 1200 cm^{-1} region and with surface temperature in the 725 - 850 cm^{-1} region. These differences hint at potential problems in the continuum formulation - temperature dependence in the self-broadened term and the magnitude of the continuum coefficients in the foreign broadened regions. We will have to closely examine ARM observations at higher water vapor amounts and temperatures to see if these differences continue.

Calibration of Radiation Codes for Climate Models

Spectrally integrated observations have also been compared with calculations from models used in GCMs (including GLA, CCM1, CCC, NMC, RPN and ECMWF) and several detailed models (e.g., AFGL's MODTRAN and LOWTRAN7, and Ellingson's narrow band model). The study has concentrated on the semi-transparent 800 - 1200 cm^{-1} region first since ICRCCM indicated that this is the most suspect portion of the spectrum due to uncertainties associated with the water vapor continuum. Large differences have been found between some models and the observations, although the differences tend to be largely systematic (see Fig. 2). Interestingly, the fractional variance of the AERI observations explained by the different models is about the same. The latter result may largely be due to the small range of precipitable water sensed during SPECTRE. Clearly, some models have deficient parameterizations of the water vapor continuum, and these will

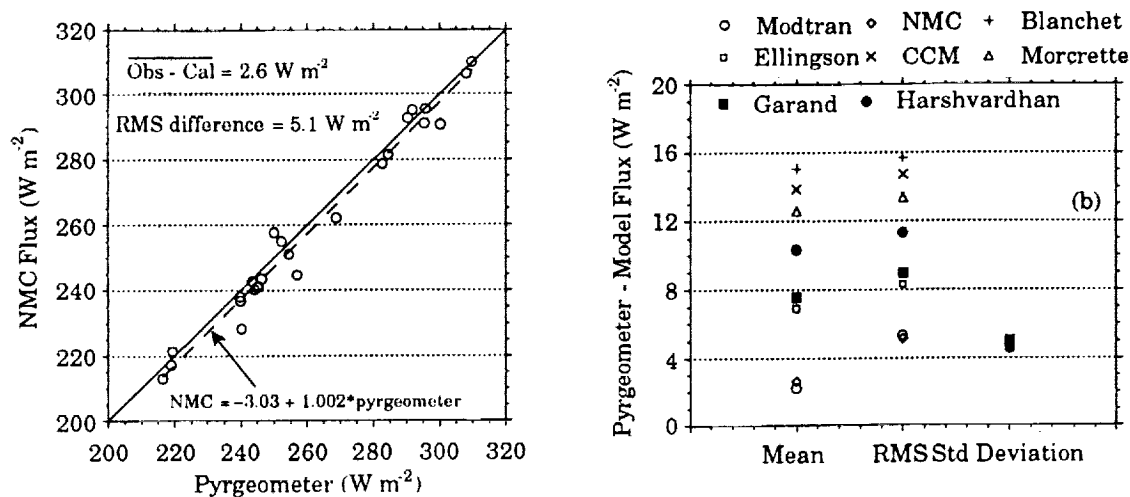


Fig. 3 Comparisons of model calculated with pyrgeometer observed clear-sky downward fluxes at the surface during SPECTRE. (a) NMC model; (b) Statistics from other models.

have to be changed in order for the models to yield correct radiances and fluxes over the full range of atmospheric conditions.

We've also begun to intercompare the model calculations with clear-sky pyrgeometer observations obtained during SPECTRE (Fig. 3). Overall, the results are quite impressive. For a 26 clear-sky set, the NMC model underestimates the observed fluxes by about $3 \text{ W} \cdot \text{m}^{-2}$ in the mean, and the rms difference is about $6 \text{ W} \cdot \text{m}^{-2}$. The other models have somewhat greater biases, but all models have about the same RMS error when the biases are removed - about $6 \text{ W} \cdot \text{m}^{-2}$. These comparisons are very consistent with the model-interferometer comparisons. Since the nominal accuracy usually ascribed to pyrgeometer data is about $\pm 5\%$, the comparisons hint that the uncertainties in the pyrgeometer data may not be as large as thought heretofore when great care is exercised in the observations.

References

Roberts, R. E., J. E. A. Selby, and L. M. Biberman, 1976: Infrared continuum absorption by water vapor in the $8\text{-}12 \mu\text{m}$ window. *Appl. Opt.*, **15**, 2085-2090.